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Williams

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[54] **ELECTROLUMINESCENT DISPLAY WITH INTEGRATED DRIVE CIRCUITRY**

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[51] **Int. Cl.**^{6} **G09G 3/10**

[52] **U.S. Cl.** **315/169.3**; 445/1; 313/505; 313/506; 313/509

[58] **Field of Search** .... 315/169.1, 169.3; 313/500, 502, 503, 505, 506; 340/324 R, 719, 784; 445/1; 437/21

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Assistant Examiner—Haissa Philogene
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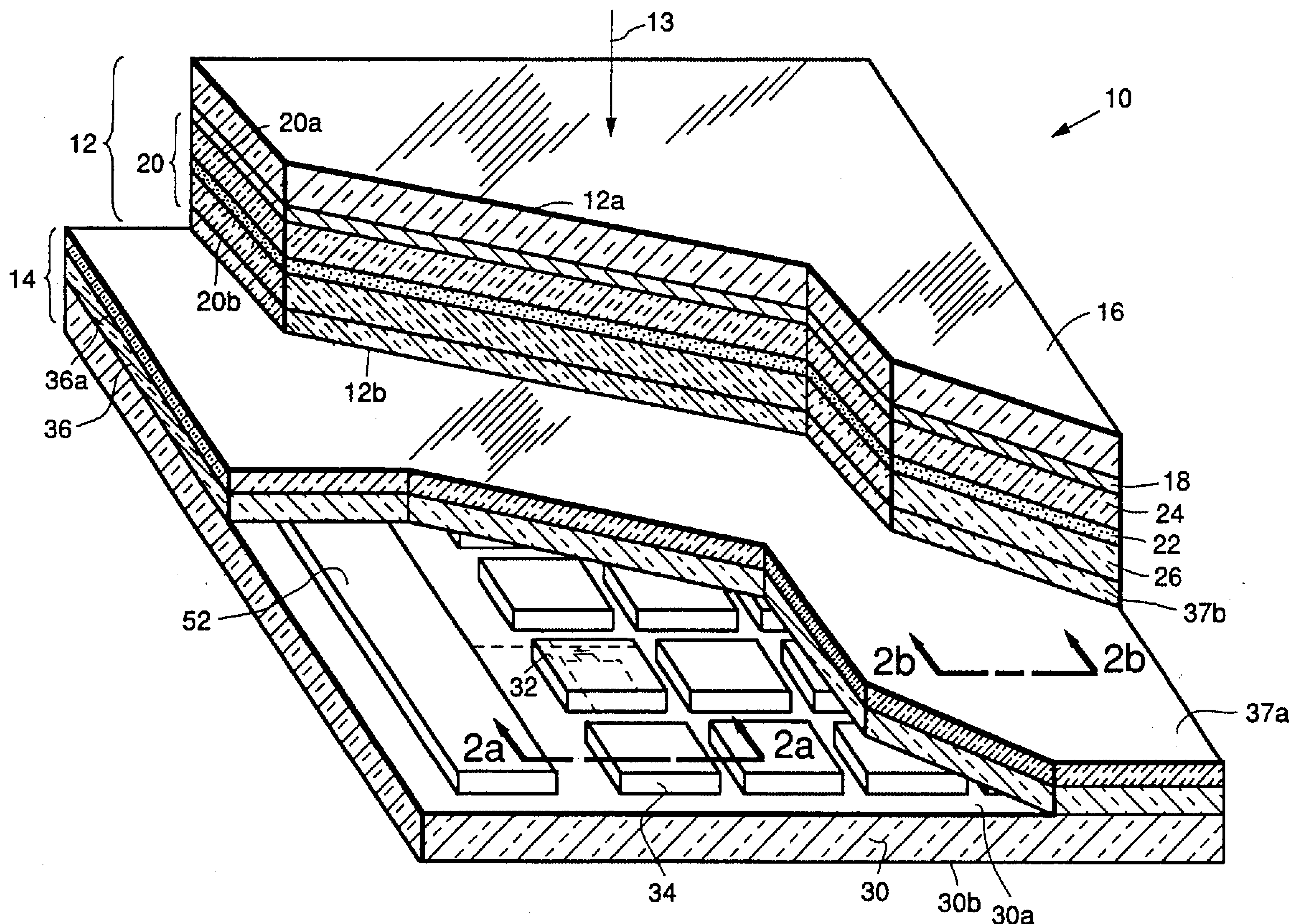
[57] **ABSTRACT**

An electroluminescent display and method of fabricating the same is described in which an active driver panel (**14**) is integrated with a processed display panel (**12**) using a unique application of semiconductor wafer technology. A microelectronic driver circuit (**32**) and back electrode (**34**) are fabricated on a semiconductor wafer (**30**) to provide a panel for driving the display. Multiple driver circuits (**32**) and respective back electrodes (**34**) may be arranged on the wafer to form an active-matrix electroluminescent display. The display panel (**12**) includes a front electrode (**18**) and an adjacent phosphor panel (**20**) for illuminating the display. The driver panel (**14**) is adhered to the display panel (**12**) using either an indium bump connection or a thermal bond, which provide both mechanical and electrical coupling between the back electrodes (**34**) and the phosphor panel (**20**). Exposure of the active devices on the driver panel to destructive high processing temperatures inherent in display panel processing is avoided.

10 Claims, 4 Drawing Sheets



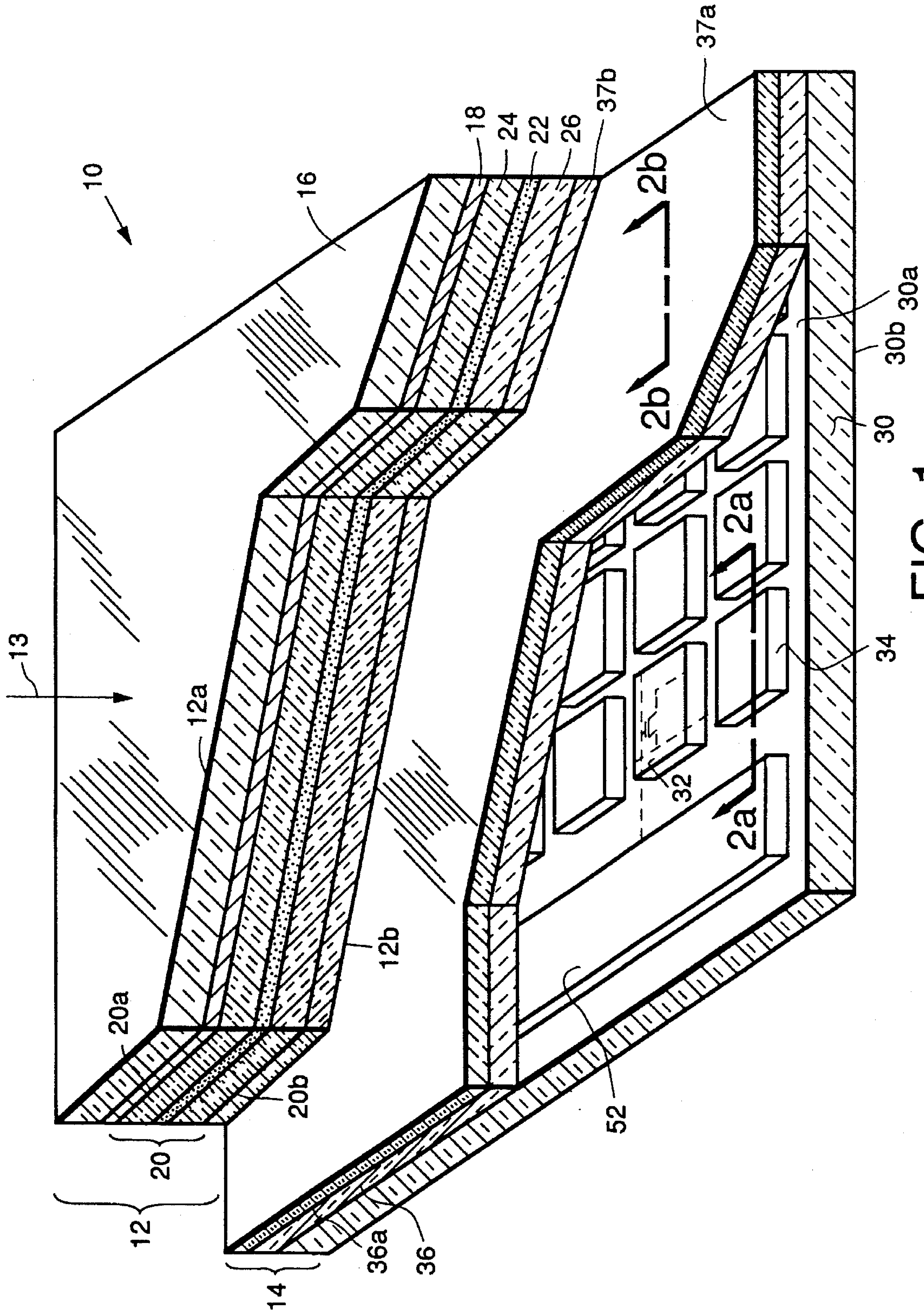


FIG. 1

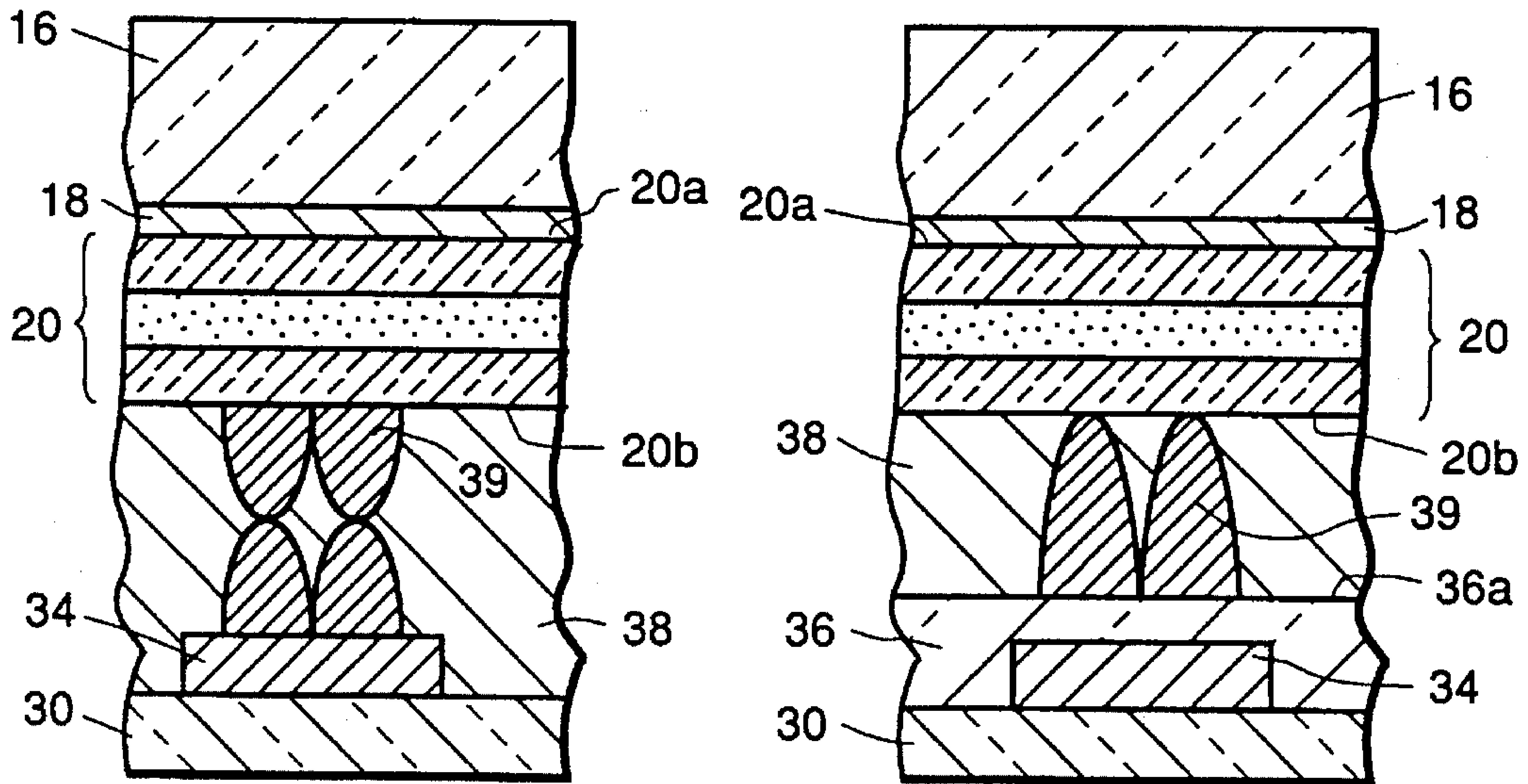


FIG. 2A

FIG. 2B

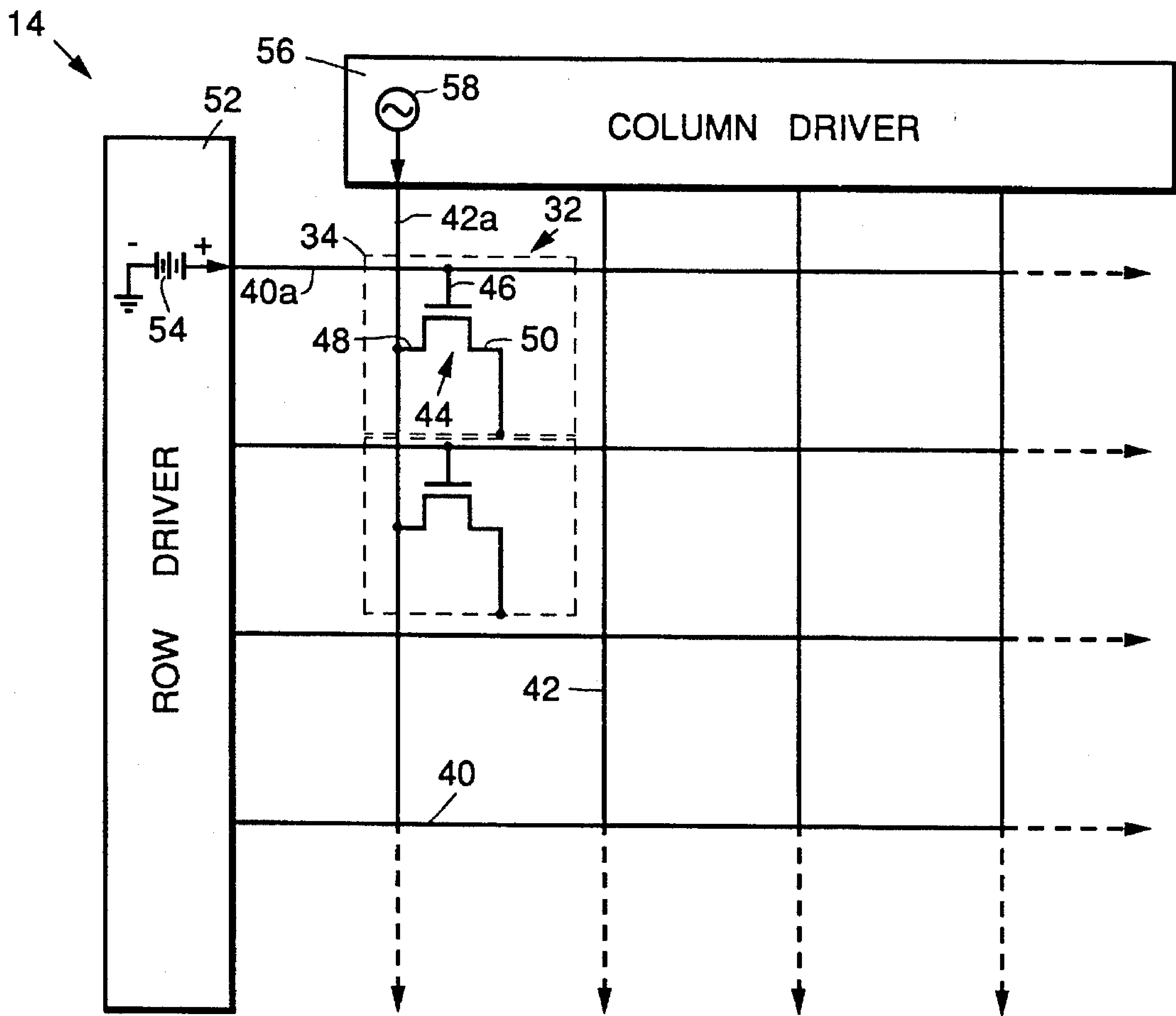


FIG. 3

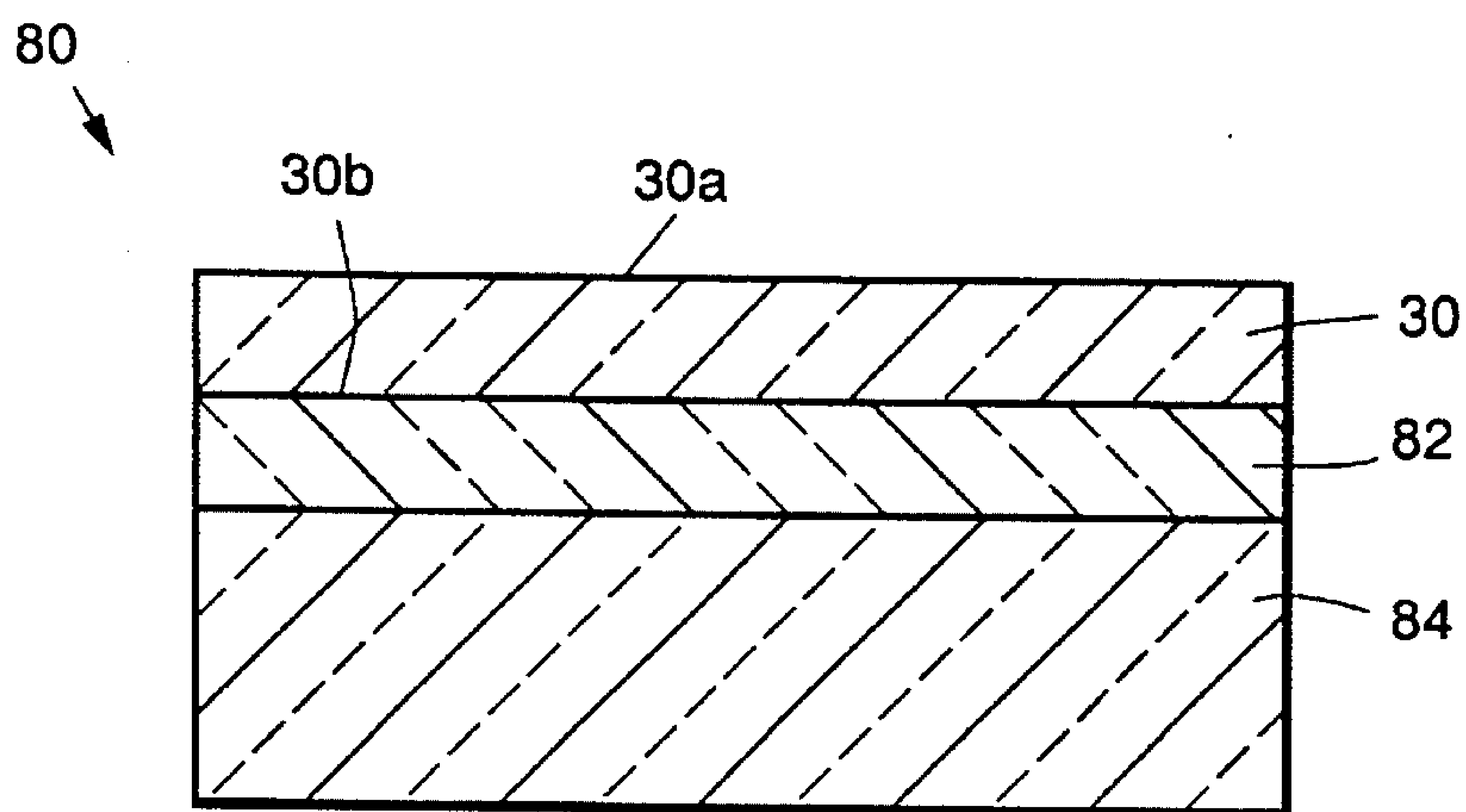


FIG. 4

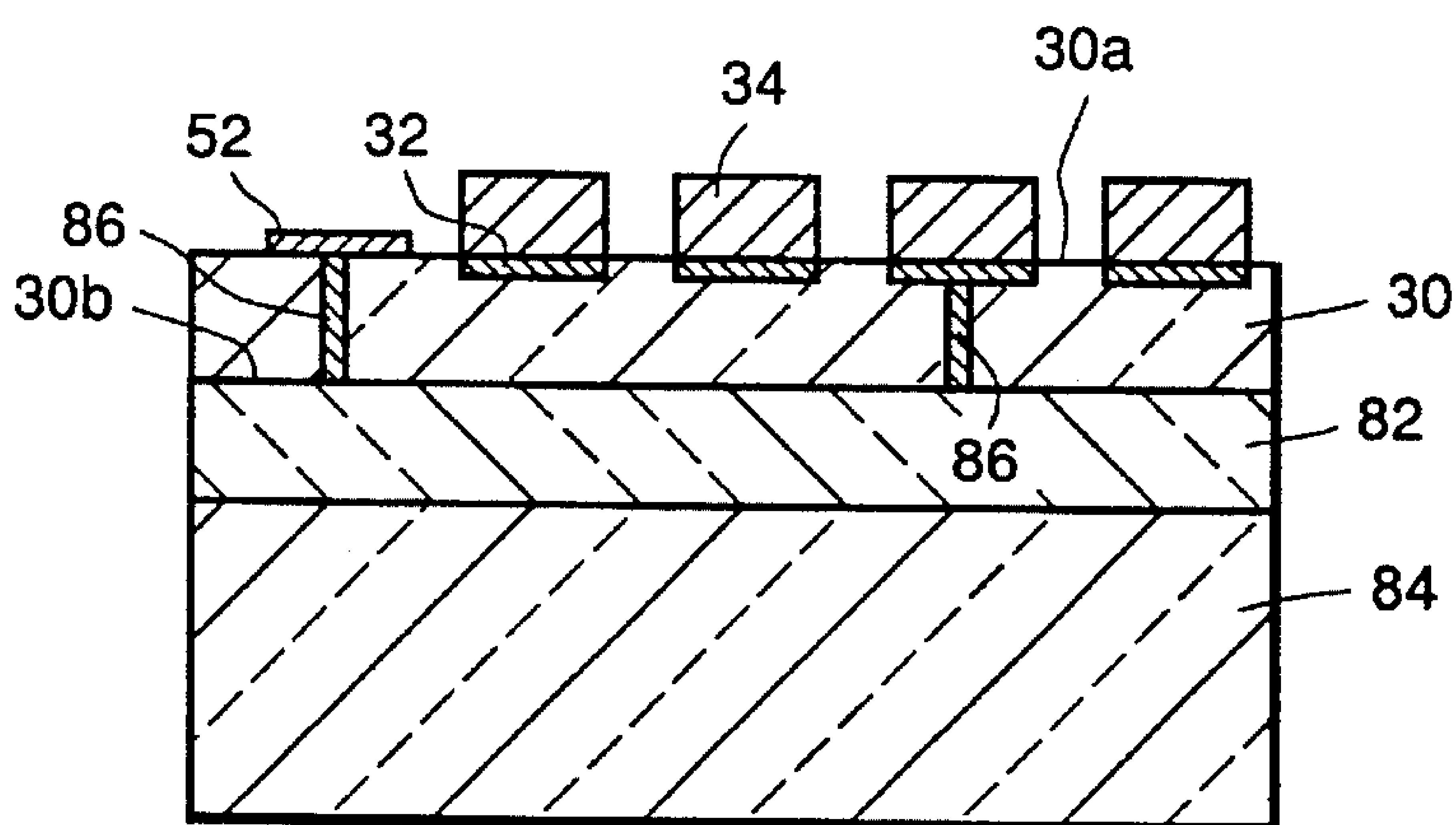


FIG. 5

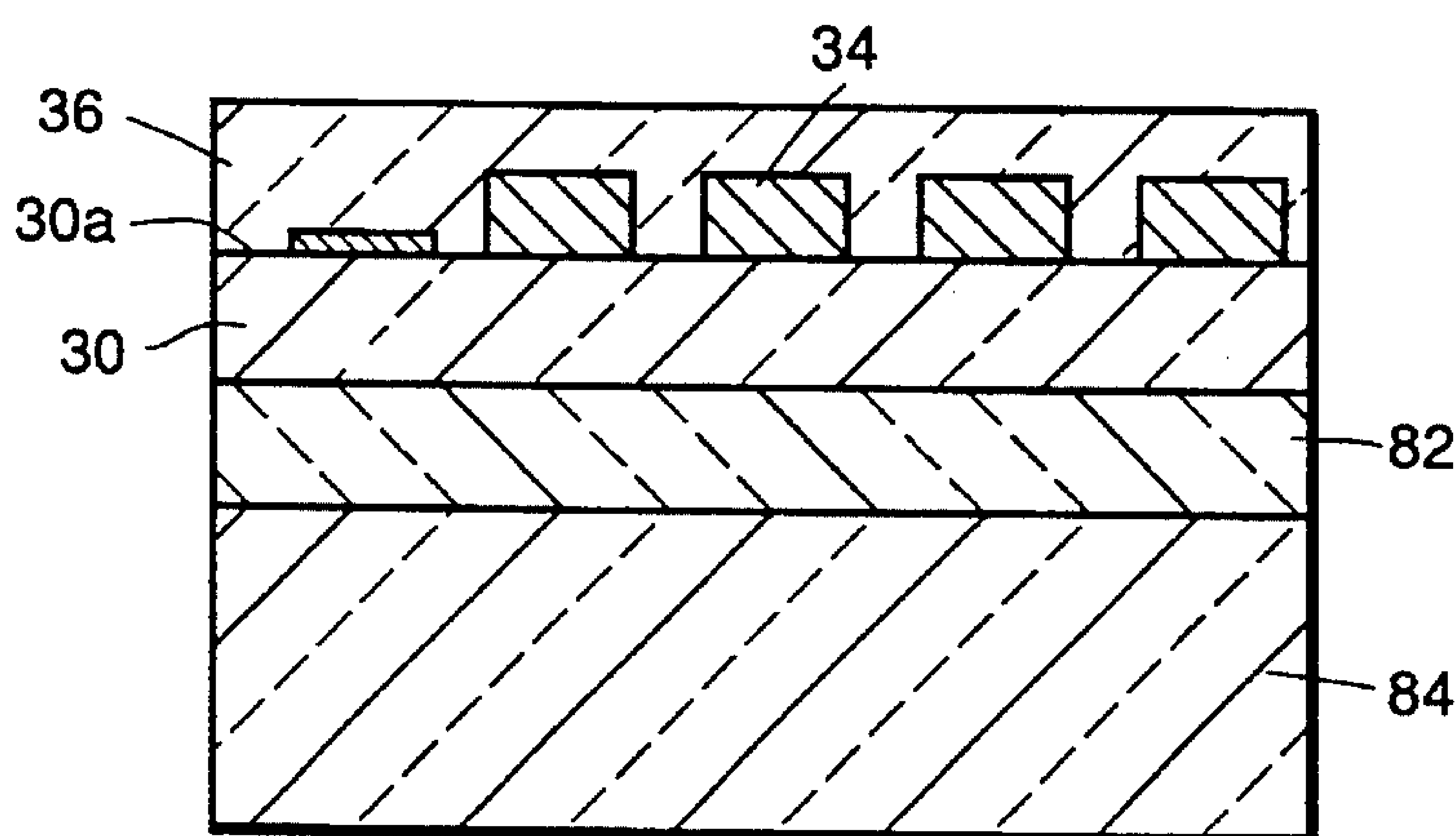


FIG. 6

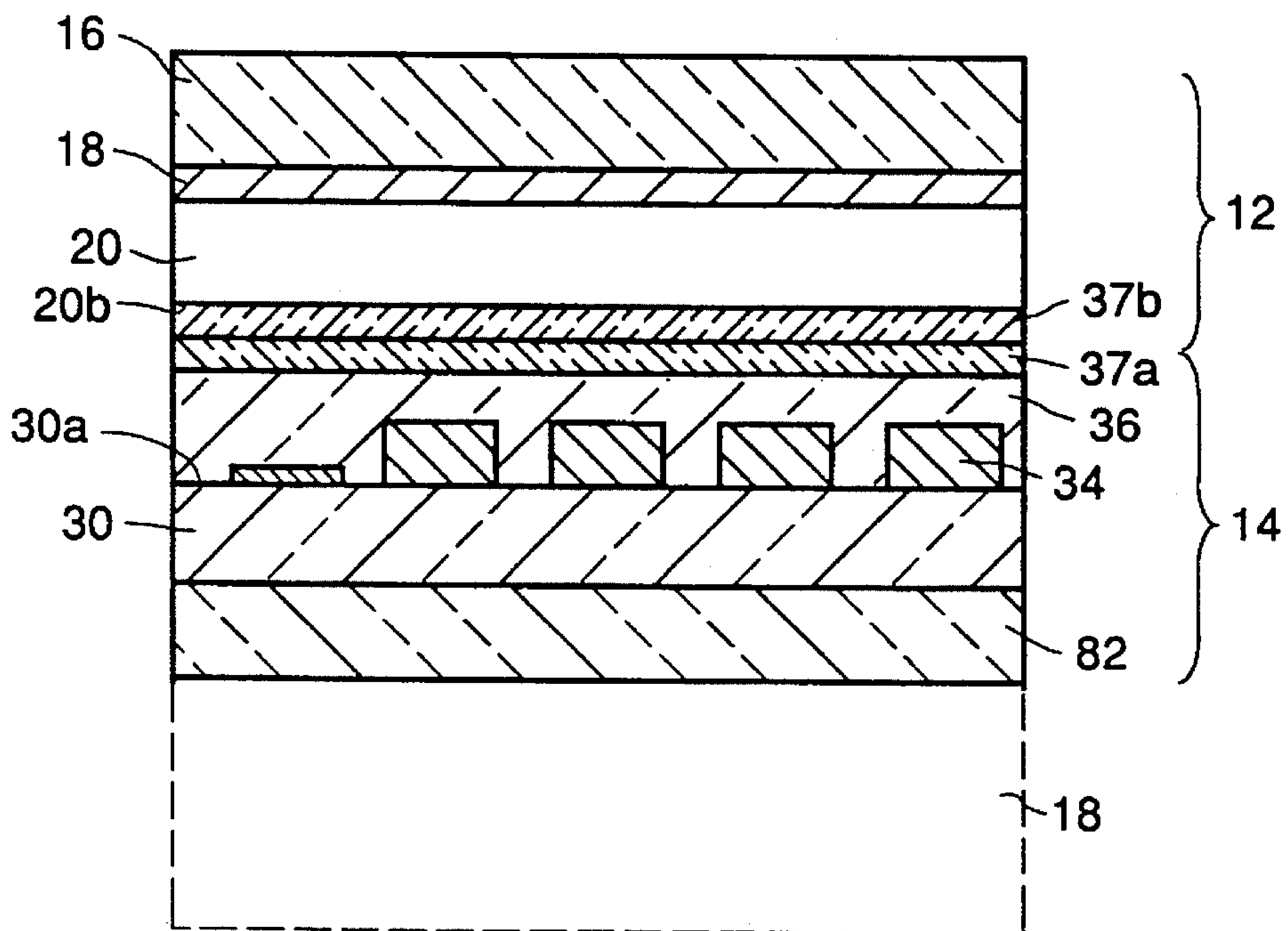


FIG. 7

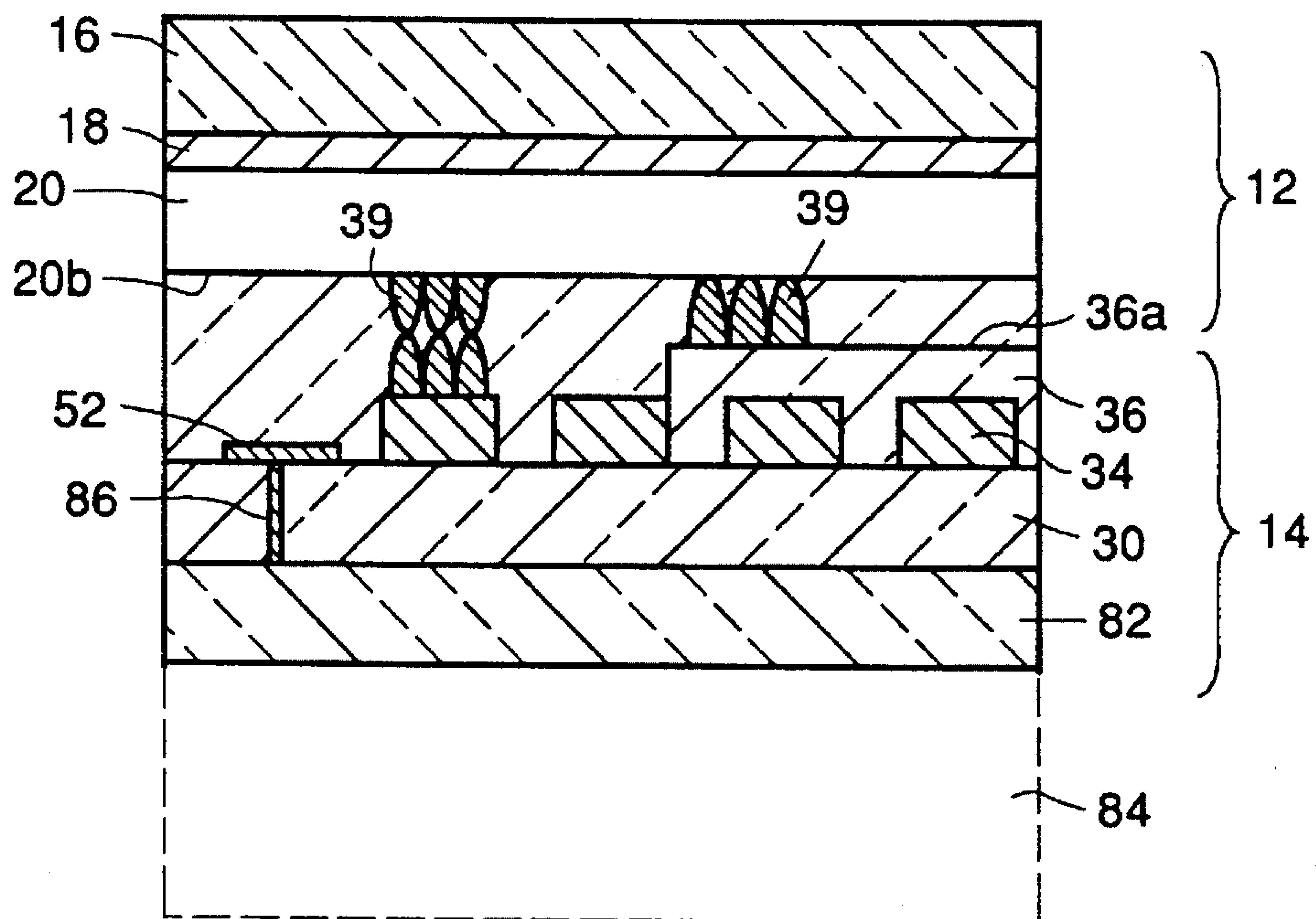


FIG.8

ELECTROLUMINESCENT DISPLAY WITH INTEGRATED DRIVE CIRCUITRY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to flat panel displays, and more particularly to an electroluminescent display and method which integrates a driver panel with a processed display panel to form an active-matrix electroluminescent display.

2. Description of the Related Art

Conventional electroluminescent displays use a passive-matrix or edge driven addressing scheme to energize a phosphor panel within the display. A typical passive-matrix electroluminescent display is described in S. Sherr, Electronic Displays §5.3.2 (2d ed. 1993). The phosphor panel is typically sandwiched between parallel row electrodes on one side of the phosphor panel and orthogonally placed parallel colur electrodes on the other side of the phosphor panel. A display element area is defined at each intersection of the row and column electrodes. A particular display element is activated by the concurrent application of voltage signals to the appropriate row and column electrodes.

Passive-matrix displays present a multitude of problems such as high power losses, slow data rates, and poor control of grey scale uniformity across the display elements of the matrix. The phosphor in electroluminescent displays typically requires a high voltage potential of between 160 and 210 volts for luminescence. This high voltage requirement, coupled with the fact that the row and column electrodes themselves define the display element areas, forces the electrodes to be relatively large in size. The large electrodes create highly resistive paths which leads to large power losses when addressing multiple display elements.

In addition to high power losses, the high resistance of the column and row electrodes results in poor control of grey scale uniformity across the display elements of the matrix. As discussed, each display element is driven by a shared row electrode and a shared column electrode. Consequently, as a particular voltage signal travels through each row and each column, the voltage signal level decreases in proportion to the resistance along the respective electrode path. As a result, a high voltage signal must be used to control grey scale modulation. In addition, the voltage signal applied to each display element varies significantly from one display element to voltage applied to each display element is critical, especially in high resolution displays with a large number of display elements.

Finally, passive-matrix displays generally suffer from slow operating speeds. The slow speed is caused in part by the large electrode size which must be used to address each display element. Further losses in speed are due to the activation of a given row only once per frame. Images on passive-matrix displays usually flicker at the frame rate because the display elements are on for only a fraction of the frame time. This can be unacceptable in high resolution video applications.

Active-matrix addressing differs from the passive-matrix structure described above by incorporating an active device, such as a switching transistor, at each display element. The active device reduces power losses by separating the electrode addressing circuitry from the actual electrodes, thus allowing the use of a smaller grey scale control voltage. Additionally, data rates are increased by a charge storage capability at each active device for providing longer "on

time" for each display element. Finally, greater grey scale uniformity is provided by independent control of the voltage signal at each display element. An active-matrix display is discussed in greater detail in S. Morozumi, "Active-Matrix Displays," 2 Society For Information Display 10.1 (1989).

The incorporation of an active drive device at each display element represents a substantial increase in the complexity of electroluminescent displays. The need for a large number of interconnections between the active devices and the display panel makes the manufacture of external driver circuit architectures impractical.

SUMMARY OF THE INVENTION

The purpose of the present invention is to provide an electroluminescent display with reduced power requirements, increased data rates, and greater control of grey scale uniformity than existing passive-matrix or edge driven electroluminescent displays. The invention integrates an active driver panel with a processed electroluminescent display panel using a unique application of semiconductor wafer technology that avoids having to design and fabricate active driver devices which are able to withstand the high processing temperatures required for phosphor panel fabrication. The display and drive panels are independently fabricated and subsequently adhered together to form an integrated electroluminescent display.

In a preferred embodiment, the display panel includes a transparent front electrode formed on a glass substrate. The front electrode is positioned adjacent to a processed phosphor panel to produce a voltage potential across the phosphor panel. On the phosphor panel, selected portions of a phosphor layer, which is disposed between insulating layers provide luminescence in response to the application of an electric field across the phosphor panel. The driver panel preferably consists of a semiconductor wafer on which a microelectronic driver circuit is formed. A back electrode, also formed on the semiconductor wafer, is operatively connected to the driver circuit to provide a voltage potential across the phosphor panel. Multiple microelectronic driver circuits and respective back electrodes are formed on the wafer in an active-matrix configuration. A row driver and a column driver for addressing each microelectronic driver circuit may also be formed on the wafer.

Finally, the driver panel is adhered to the display panel using either an indium bump connection or a thermal bond to provide both mechanical and electrical coupling between the back electrodes and the phosphor panel.

In establishing an indium bump connection, indium bumps are formed on the back electrodes and/or the phosphor panel. Alternatively, if an overglass layer is applied over the back electrode to provide a planarized surface, the indium bumps may be formed on the overglass layer.

In creating a thermal bond, a first bonding insulating layer, formed on the phosphor panel, is thermally fused to a second bonding insulating layer on the driver panel at a temperature between 170° C. and 350° C.

These and other features and advantages of the invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings, in which:

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cutaway perspective view illustrating an electroluminescent display embodying the present invention;

FIG. 2A is a sectional view of a portion of the display, taken at line 2—2 of FIG. 1, showing one embodiment of the indium bump connection;

FIG. 2B is a sectional view of a portion of the display, taken at line 2—2, showing a second embodiment of the indium bump connection;

FIG. 3 is a schematic diagram of the active matrix driver panel, particularly illustrating the interconnections between the microelectronic driver device, column bus lines, and row bus lines; and

FIGS. 4–8 are simplified sectional views illustrating a method of fabricating the display according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As illustrated in FIG. **1**, an electroluminescent display **10** embodying the present invention includes a display panel **12** and a driver panel **14** for electrically driving the display panel **12**. The display panel **12**, which can be viewed from direction **13**, includes a substrate **16** made of a transparent material such as glass. A front electrode **18**, preferrably made of a transparent conductive material such as indium tin oxide (ITO), is formed on the inner surface of substrate **16**. A phosphor panel **20**, having a outer surface **20***a* and an inner surface **20***b*, is positioned along the opposite side of the front electrode **18** from substrate **16**. The phosphor panel **20** is adhered to the front electrode **18** by a transparent adhesive.

The phosphor panel **20** includes an active medium such as a zinc sulfur based phosphor layer **22**. The phosphor layer **22** preferably has a thickness of approximately 5000 angstroms and is sandwiched between a first insulating layer **24** and a second insulating layer **26**. The insulating layers **24**, **26** can be made from a dielectric material such as silicon dioxide, silicon nitrate, aluminum oxide, or titanium oxide. Preferably, insulating layers **24**, **26** each have a thickness of between 2000 and 2500 angstroms.

The display panel **12** as described is available from commercial flat panel display suppliers such as Planar Systems Inc. of Beaverton, Oregon. The described display panel is the preferred embodiment of the invention, but other known types of display panels fabricated from a wide variety of other materials may be used within the scope of the invention.

The driver panel **14** consists of a semiconductor wafer **30** having an inner surface **30***a* and an outer surface **30***b*. The preferred material for the semiconductor wafer **30** is monocrystalline (single crystalline or bulk) silicon, although other semiconductor materials such as gallium arsenide, cadmium selenide or cadmium telluride may be used.

A microelectronic driver circuit **32**, shown by dotted lines in FIG. **1**, is formed on the inner surface **30***a* of semiconductor wafer **30** using standard microcircuit fabrication techniques. Alternatively, the microelectronic driver circuit **32** or portions thereof can be formed on the outer surface **30***b* of the semiconductor wafer **30** using similar fabrication techniques. In the latter case, electrical contact between the inner and outer surfaces **30***a* and **30***b* can be made with standard conductive interconnects (not shown) extending through the semiconductor wafer **30**. The microelectronic driver circuit **32**, and the fabrication thereof, is described in greater detail below in connection with FIG. **3**.

A back electrode **34** is desposited on the inner surface **30***a* of the semiconductor wafer **30**. Preferably, back electrode **34** is made of a high quality reflective aluminum which provides both conductivity as well as increased display brightness. The back electrode **34** is electrically connected to the microelectronic driver circuit **32**. An insulating material (not shown) may be used to prevent undesirable shorting between the microelectronic driver circuit **32** and the back electrode **34**.

Multiple back electrodes **34** and microelectronic driver circuits **32** can be arranged in any desired configuration. Additional circuitry, such as row driver **52** and column driver **56**, can also be formed on semiconductor wafer **30** for matrix addressing of microelectronic driver circuits **32**.

In the preferred configuration as illustrated in FIG. **1**, the back electrodes **34** and respective microelectronic driver circuits **32** are arranged in a matrix array to form an active-matrix electroluminescent display (AMEL). Any number of back electrodes **34** and respective driver circuits **32** can be used. A practical display might include, for example, 1,310,720 back electrodes **34** and driver devices **32** arranged in a 1,280×1,024 matrix.

Alternatively, although not illustrated, the back electrodes **34** can be arranged as segments which are selectively activated to form numerals or alphanumeric characters, or as an array not ordered in rows and columns, but in other patterns.

An overglass layer **36** is preferably deposited or formed over the back electrodes **34**. The overglass layer **36** is preferably made of any dielectric material of the types mentioned above. The overglass layer **36** provides a planarized surface **36***a* for enhancing the adhesion or bonding of the driver panel **14** to the display panel **12**. The driver panel **14** is adhered to the display panel **12** to provide electrical and mechanical coupling between the back electrodes **34** and the inner surface **20***b* of phosphor panel **20**.

In the embodiment illustrated in FIG. **1**, electrical and mechanical coupling between the display and driver panels **12** and **14** is accomplished using a thermal bond. A first bonding insulating layer **37***a* is formed on the inner surface **36***a* of the overglass layer **36**. If an overglass layer **36** is not used, the first bonding insulating layer **37***a* is formed directly over back electrodes **34** on the inner surface **30***a* of semiconductor wafer **30**. A second bonding insulating layer **37***b* is formed on the inner surface **20***b* of phosphor panel **20**. Insulating layers **37***a*, **37***b* can be formed from any dielectric material of the type mentioned above, but are preferably silicon dioxide or silicon nitrate having a thickness of approximately 500 angstroms.

The first bonding insulating layer **37***a* is thermally fused to the second bonding insulating layer **37***b*. The fusion between layers **37***a* and **37***b* provides both a strong mechanical bond between the driver panel **14** and the display panel **12**, and capacitive coupling between the back electrodes **34** and the inner surface **20***b* of the phosphor panel **20**.

Alternate embodiments of the present invention are shown in FIGS. 2A and 2B. The embodiment of FIG. 2A establishes direct resistive coupling and mechanical adhesion between the display and driver panels through indium bump connections **38**. The indium bumps **39** can be fabricated directly on the back electrodes **34** and/or inner surface **20***b* of the phosphor panel **20**. Alternatively, if an overglass layer **36** is desired for planarization, the indium bumps **39** may be fabricated directly on the inner surface **36***a* of the overglass layer **36** as shown in the embodiment of FIG. 2B. In such cases, the overglass layer **36** between the indium bumps **39** and the back electrodes **34** acts as a series capacitance.

An equivalent schematic diagram of the driver panel **14** is shown in FIG. **3**. Multiple microelectronic driver circuits **32** and respective back electrodes **34**, shown in dotted lines, are arranged in a square matrix configuration. Each microelectronic driver circuit **32** includes a row bus line **40**, a column bus line **42**, and a microelectronic driver device **44**. The bus lines **40**, **42** may be made of aluminum or other suitable metallizations, or alternatively may be formed as heavily doped, electrically conductive lines in the material of the semiconductor wafer **30**. The microelectronic driver device **44** is preferably a high voltage thin film MOSFET transistor, although other types of transistor devices or configurations may be used.

A respective row bus line **40a** is connected to the gate **46** of microelectronic drive device **44**. The respective column bus line **42*a*** is connected to the source **48** of the microelectronic driver device **44**, and the drain **50** of the microelectronic driver device **44** is connected to the respective back electrode **34**. Additionally, a storage capacitor (not shown) may be added between the drain **50** and ground reference for powering the electrode after the driver device **44** has been turned off.

Row driver **52** and column driver **56** microelectronic circuits may be fabricated directly on the inner surface **30*a*** of semiconductor wafer **30*b***. The circuits **52** and **56** are fabricated at the same time as, and using the same processing technology as, the microelectronic driver circuits **32**. External connections to circuits **52** and **56** can be made through electrical interconnects (not shown) extending through semiconductor wafer **30**. Alternatively, circuits **52** and **56** may be fabricated on the outer surface **30b** of semiconductor wafer **30** or on an external substrate that is electrically connected to the wafer's outer surface **30*b***.

In addition to including row driver **52** and column driver **56**, other integrated microcircuits can be integrated which provide clock, partitioning, housekeeping and other functions. This enables substantially all of the microelectronic circuitry for the electroluminescent display **10** to be integrally fabricated on the display.

Row driver **52** sequentially applies a select signal **54** to the row bus lines **40**. Column driver **56** applies a data signal **58** to the column bus lines **42** which determines the voltage level applied to the back electrodes **34**, and thus the corresponding illumination of the phosphor panel **20**. The row bus lines **40** are sequentially scanned to generate a graphic image.

The select signal **54**, applied to the row bus line **40a** through row driver **52**, provides the necessary voltage to the gate **46** for turning on the driver device **44**. During the time in which the select signal **54** is applied to gate **46**, driver device **44** provides a low impedance path between the source **48** and the drain **50**. The data signal **58**, simultaneously applied to the column bus line **42*a*** through column driver **56**, travels through the driver device **44** to back electrode **34**. The data signal **58** is preferably a variable value in proportion to the grey scale level to be displayed on phosphor panel **20**.

The back electrodes **34** are individually and selectively switched to a range of voltages as described above. When a voltage potential, and thus an electric field, is created between the back electrode **34** and the front electrode **18**, the phosphor layer **22** illuminates. More specifically, the application of a voltage potential causes electrons at the negatively-biased electrode to gain enough kinetic energy to impact and thereby excite the phosphor **22**, causing it to luminesce.

A preferred method of fabricating the electroluminescent display **10** is illustrated in FIGS. –**8**. In FIG. **4**, a bonded structure **80** is provided, consisting of the semiconductor wafer **30** with an oxide layer **82** formed on its outer surface **30*b***. A carrier substrate **84** is thermally fused to the wafer's inner surface **30*b*** using the oxide layer **82** as the bonding medium. Preferably, the thermal fusion is accomplished at a temperature of approximately 1000° C.

The semiconductor wafer **30** has a thickness of approximately 2–8 micrometers, which allows for double sided fabrication and enhanced performance as is known in the art. The carrier substrate **84** is preferably formed of silicon with a thickness of approximately 500 micrometers, making it sufficiently durable to support the semiconductor wafer **30** through standard processing steps. The oxide layer **82** is typically silicon dioxide having a thickness of approximately one micrometer. A bonded structure **80** which is suitable for practicing the present invention is commercially available from many suppliers, such as Shinetsu Handotai of Tokyo, Japan.

At the next stage of fabrication, illustrated in FIG. **5**, microelectronic driver circuits **32** which include the microelectronic driver devices **44**, row bus lines **40**, and column bus lines **42**, are fabricated on the inner surface **30*a*** of semiconductor wafer **30** using standard microcircuit fabrication techniques. It is to be understood that microelectronic driver circuits **32**, or portions thereof, may alternatively be fabricated on the outer surface **30*b*** of semiconductor wafer **30**. In the latter case, electrical interconnects **86** are formed through the semiconductor wafer **30** from the driver circuits **32**.

The electrical interconnects **86** are created by patterning the inner surface **30*a*** of the semiconductor wafer **30** and etching openings using conventional photolithographic processing. A metal is deposited in each opening to form the interconnects **86**, which provide electrical contacts from the inner surface **30*a*** to the outer surface **30*b*** of the semiconductor wafer **30**.

Additionally, row drivers **52** and column drivers **56** can be fabricated on the wafer's inner surface **30*a*** using the same standard fabrication techniques as discussed above. Additional microelectronic devices or structures may also be fabricated on the wafer's inner surface **30*a*** .

In FIG. **5**, the back electrodes **34** are also deposited on the wafer's inner surface **30*a*** . The back electrodes **34** may need to be sufficiently insulated (not shown) from the driver circuit **32** to avoid undesirable shorting between them.

An overglass layer **36** can also be deposited on the wafer's inner surface **30*a*** , as shown in FIG. **6**. This step is optional, but creates a planarized surface that enhances the bonding between the driver panel **14** and the display panel **12**.

The fabrication process for a typical phosphor panel **20** requires an annealing temperature of between 500° C. and 1000° C. Microelectronic driver circuits **32** made from semiconductor material are not able to withstand these elevated processing temperatures and must be independently fabricated and subsequently integrated with the phosphor panel **20** at a much lower temperature.

FIGS. **7** and **8** illustrate two low temperature methods of adhering the wafer's inner surface **30*a*** to the phosphor panel's inner surface **20*b***. In one method, the wafer's inner surface **30*a*** is thermally bonded to the phosphor panel's inner surface **20*b***. The thermal bonding process, illustrated in FIG. **7**, includes forming a first bonding insulating layer **37a** on the wafer's inner surface **30*a*** and a second bonding insulating layer **37*b*** on the phosphor panel's inner surface

20*b*. The first bonding insulating layer **37***a* is then thermally fused to the second bonding insulating layer **37***b* at a temperature between 170° C. and 350° C., and preferably at 200° C. in an oxygen environment. This low temperature fusion bonding process prevents destruction of the processed semiconductor driver circuit **32**.

Another method of adhering the semiconductor wafer **30** to the display panel **20** is to indium bump connect the back electrodes **34** to the phosphor panel's inner surface **20***b*. As shown in FIG. **8**, the indium bumps **39** are deposited directly on either or both the back electrodes **34** and the second surface **20***b* of phosphor panel **20**. If an overglass layer **36** is used, the indium bumps can be deposited on the inner surface **36***a* of the overglass layer **36**. The driver panel **14** and display panel **12** are then pressed together, with or without the intermediary of an adhesive, to form both electrical and mechanical coupling.

In the final step, the carrier **84** is removed using well known etching techniques. This completes the integration of the driver circuit **14** with the display panel **12**. Additional microelectronic driver circuits **32** (not shown) can be subsequently formed on the wafer's outer surface **30***b* as desired.

While preferred embodiments of the invention have been shown and described, numerous variations and alternate embodiments will be apparent to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

I claim:

1. An integrated electroluminescent display comprising:

(a) a display panel, wherein said display panel comprises:

a substrate;

a front electrode array formed on said substrate; and

a phosphor panel having an outer surface and an inner surface, said outer surface positioned adjacent said front electrode array;

(b) a driver panel for electrically driving said display panel, wherein said driver panel comprises:

a semiconductor wafer having an inner surface;

a microelectronic driver circuit formed on said semiconductor wafer; and

a back electrode array deposited on said inner surface of said wafer and operatively connected to said microelectronic driver circuit and wherein said back electrode array is electrically coupled to said display panel; and

(c) a plurality of bumps for electrically coupling said back electrode array of said driver panel to said display panel, wherein at least some of said bumps are in contact with said inner surface of said phosphor panel and extend towards said back electrode array.

2. A device as recited in claim **1**, wherein said bumps are indium bumps.

3. A device as recited in claim **1**, wherein said phosphor panel comprises:

a first insulating layer;

a second insulating layer spaced from said first insulating layer; and

a phosphor layer disposed between said first insulating layer and said second insulating layer.

4. A device as recited in claim **1**, wherein at least some of said bumps extend from said back electrode array and make contact with said bumps extending from said inner surface of said phosphor panel.

5. A device as recited in claim **1**, further comprising an overglass layer formed on said inner semiconductor wafer surface over said back electrode array, wherein said bumps extending from said panel are also in contact with said overglass layer.

6. A device as recited in claim **1**, wherein said microelectronic driver circuit comprises a plurality of microelectronic driver circuits and said back electrode array comprises a plurality of back electrodes, said plurality of said driver circuits and said back electrodes arranged in a matrix configuration.

7. A device as recited in claim **1**, wherein said microelectronic driver circuit comprises:

a microelectronic driver device;

a row bus line for electrically controlling the operation of said microelectronic driver device; and

a column bus line for electrically communicating a signal through said microelectronic driver device to said back electrode.

8. A device as recited in claim **1**, wherein said semiconductor wafer is a monocrystalline silicon wafer.

9. A method of fabricating an electroluminescent display from a display panel and a driver panel, comprising the step of mechanically and electrically coupling said display panel to said driver panel by thermally bonding said driver panel to said display panel, wherein said thermal binding strip comprises:

forming a first layer of bonding insulating material on an inner surface of said driver panel;

forming a second layer of bonding insulating material on an inner surface of said display panel; and

thermally fusing together said first and second bonding insulating layers.

10. The method of claim **9**, further comprising the step of forming an overglass layer between said inner surface of said driver panel and said first layer of bonding insulating material.

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